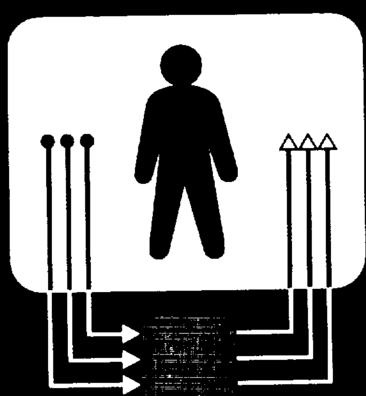
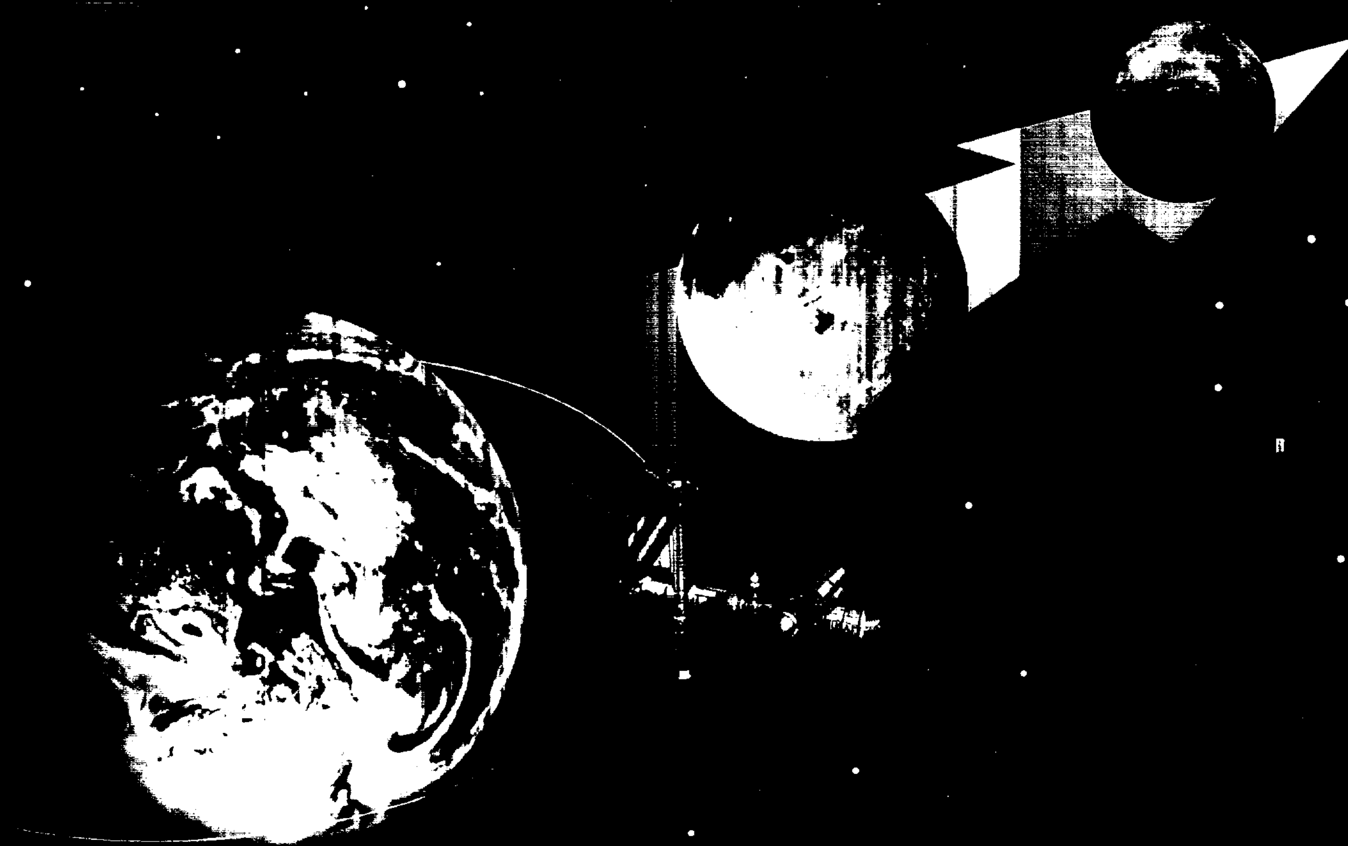
TM-4756

Advanced Environmental Monitoring and Control Program

Technology Development Requirements





Advanced Environmental Monitoring and Control Program

Technology Development Requirements

Environmental Monitoring and Controls Workshop

May 1996

Pasadena, California

This document was prepared for the NASA Life and Biomedical Sciences and Applications Division (LBSAD) in an effort coordinated by the Jet Propulsion Laboratory.

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TECHNOLOGY DEVELOPMENT REQUIREMENTS

FOREWORD

Human missions in space, from the International Space Station on towards potential human exploration of the moon, Mars and beyond into the solar system, will require advanced systems to maintain an environment supporting human life. These systems will have to recycle air and water for many months or years at a time, and avoid harmful chemical or microbial contamination. A critical need for supporting humans in exploration missions is knowledge of the environment in which crew members will live, as well as knowledge of the systems providing their life support. This knowledge will take the form of assessing the quality of cabin and life support system air, monitoring drinking and process water for contamination, and monitoring the entire environment to assess the type and extent of any microbial populations.

NASA's Advanced Environmental Monitoring and Control program has the mission of providing future spacecraft with advanced, integrated networks of microminiaturized sensors to accurately determine and control the physical, chemical and biological environment of the crew living areas. The success of this mission is essential for supporting humans on future space exploration missions. In order that this program be successful, a thorough understanding and accounting of the needs for environmental monitoring and control within future spacecraft is essential.

This document sets out the current state of knowledge for requirements for monitoring the crew environment for space exploration. The requirements are based on two distinct sources of higher-level requirements: requirements for crew health and requirements for monitoring life support systems. Crew health requirements are being updated continuously through better understanding gained from toxicology research and flying missions in space, and the shape of advanced life support systems for future exploration missions is under a great deal of change also due to research. The environmental monitoring and control requirements which serve these two disciplines will no doubt change in the future. Nonetheless, the Advanced Environmental Monitoring and Control program is an advanced technology development program which must rest on a firm foundation of requirements: the technologies developed under the program's authority must meet the needs of future life support systems and must be responsive to the needs of monitoring crew health. In addition, these technologies must meet the needs of all future space systems - they must be inexpensive, both to purchase and to operate, and they must be lightweight and use few resources. Using these requirements to continue to push the state of the art in miniaturized sensor and control systems will produce revolutionary technologies to enable a complete, detailed knowledge of the crew environment in future exploration missions.

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Advanced Environmental Monitoring and Control Program

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1 INTRODUCTION

This document is written to establish a framework for identifying and evaluating technology needs in the area of environmental monitoring and control in next generation spacecraft. The involvement and participation of technologists in the government, industry and universities have made this manual a needed guide for pursuing the development of mission-enabling technologies for space missions in the 21st century. Revisions to this document will be necessary as designs change or are refined, and as new health hazards are recognized.

The state of the art of environmental monitoring technology is found to be at varying levels of maturity. At the writing of this document, air monitoring technology seems to be most mature, followed closely by water, while microbial monitoring technology is advancing at an extremely rapid pace. The treatments of these technologies in this document reflect these variations in state of the art.

1.1 List of Acronyms

ADI	adult daily intake
AI	artificial intelligence
CFU	colony-forming units
CHeCS	Crew Health Care Systems
CNS	central nervous system
COD	chemical oxygen demand
COT	Committee On Toxicology
CMP	combined mass parameter
CPP	combined performance parameter
ECLSS	Environment Control Life Support Systems
EMCS	environmental monitoring and control system
EPA	Environmental Protection Agency
ETP	environmental tolerance parameter
EVA	extravehicular activity
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
LEO	low-earth orbit
LQL	lower quantification limit
MCL	Maximum Concentration Level (see also SMCL)
MSFC	Marshall Space Flight Center
MTBF	mean time between failures
MTBM	mean time between maintenance
MTTR	mean time to repair
NOEL	no-effect level
ppb	parts per billion

ppm	parts per million
SF	safety factor
SMAC	Spacecraft Maximum Allowable Concentration
SMCL	Spacecraft Maximum Concentration Level (sometimes abbreviated MCL)
TLV	threshold limit value
TOC	total organic carbon
T-value	toxicity value
UF	uncertainty factor
UQL	upper quantification limit

1.2 Objectives

The technical effort that culminated in this document was focused towards the following objectives of significance to the National Aeronautics and Space Administration (NASA):

(A) To define sets of environmental monitoring and control requirements for a number of human space missions based on prioritization and risk assessment.

(B) To define a technology maturity metric for environmental monitoring and control technologies as a framework for comparing and expressing the results of technology development relevant to NASA.

1.3 Scope

This effort is limited to environmental monitoring and control systems, and component technologies. It does not deal with life-support systems and component technologies which operate in a highly interactive and interdependent manner with the former, although it is recognized that the issues of overlap and interactivity with life-support system technology will likely be addressed in future versions of this document. Nor does it deal with radiation effects or noise levels, which for the time being are outside the scope of this effort. This document establishes spacecraft environmental monitoring and control requirements for the guidance of current and future technology developers. It is the result of a consensus within the technological community regarding the necessary monitoring and control requirements for long-duration human missions. The data and methodology contained in this document will very likely be useful throughout the iterative cycles of technology development and technology assessment, culminating in selection of technology candidates for mission insertion. As such, this document does not assess present technologies.

It is further recognized that future versions of this document will not only track technological development, but also redefine or further define mission requirements, and advance mission-relevant toxicological research, as referenced in updated documentation for such activities as the International Space Station.

1.4 Approach

The approach adopted to achieve the twin objectives of (a) establishing mission-driven requirements for environmental monitoring and control, and (b) illustrating a flexible framework for system requirements and technology assessment, is illustrated by the schematic diagram in Figure 1.

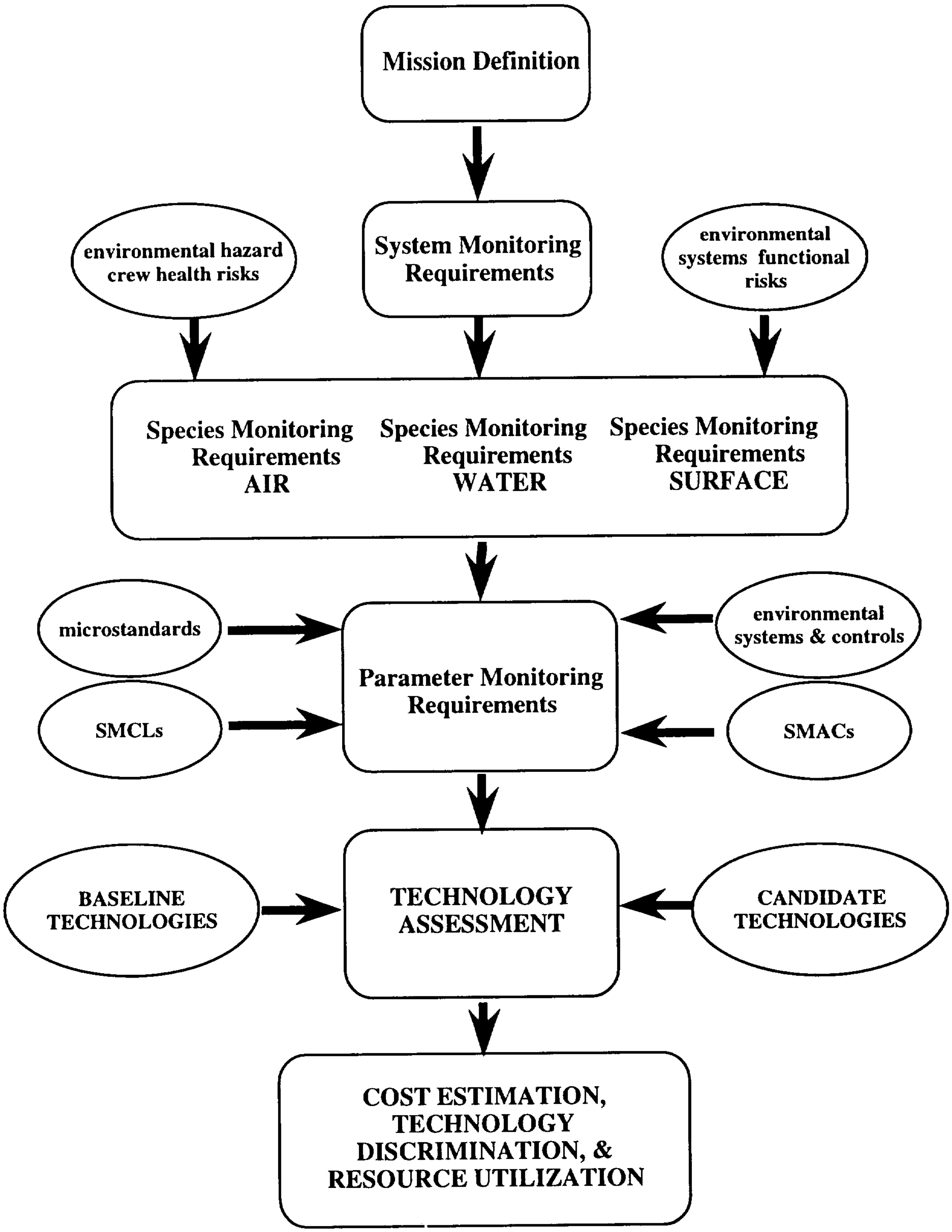

Figure 1. Schematic Diagram for Establishing System Requirements and Technology Assessment.

First, various human space missions of interest are identified in as much detail as possible to define environmental monitoring and control requirements. Following this, the environmental monitoring and control system is conceptualized to identify its interfaces, especially with the life support system. Having defined the human habitat space called cabin, environmental monitoring requirements are expressed at the system level. These are then expanded into requirements for chemical-species monitoring in air, water, and on surfaces, and for particulate (dust) monitoring and control. In order to arrive at the specific requirements for individual monitoring functions (called Parameter Monitoring Requirements), it is necessary to know the region of interest for the various measurements such as cabin temperature, cabin pressure, concentration of major and trace constituents in air, water, *etc.* For airborne contaminants, Spacecraft Maximum Allowable Concentrations (SMACs) have been set by the Johnson Space Center Toxicology Group in collaboration with the National Research Council. These quantities ought to be extended to include longer duration missions. There are also Spacecraft Maximum Contamination Levels (SMCLs) for contaminants in water. With the help of these limit values, the operating ranges of the monitoring instruments are defined.

2 ORGANIZATION OF REQUIREMENTS

Environmental monitoring and control requirements are organized in this document in the manner illustrated in Figure 2. This 3-D illustration implies a hierarchy of mission, major monitoring categories and actual monitored parameters.

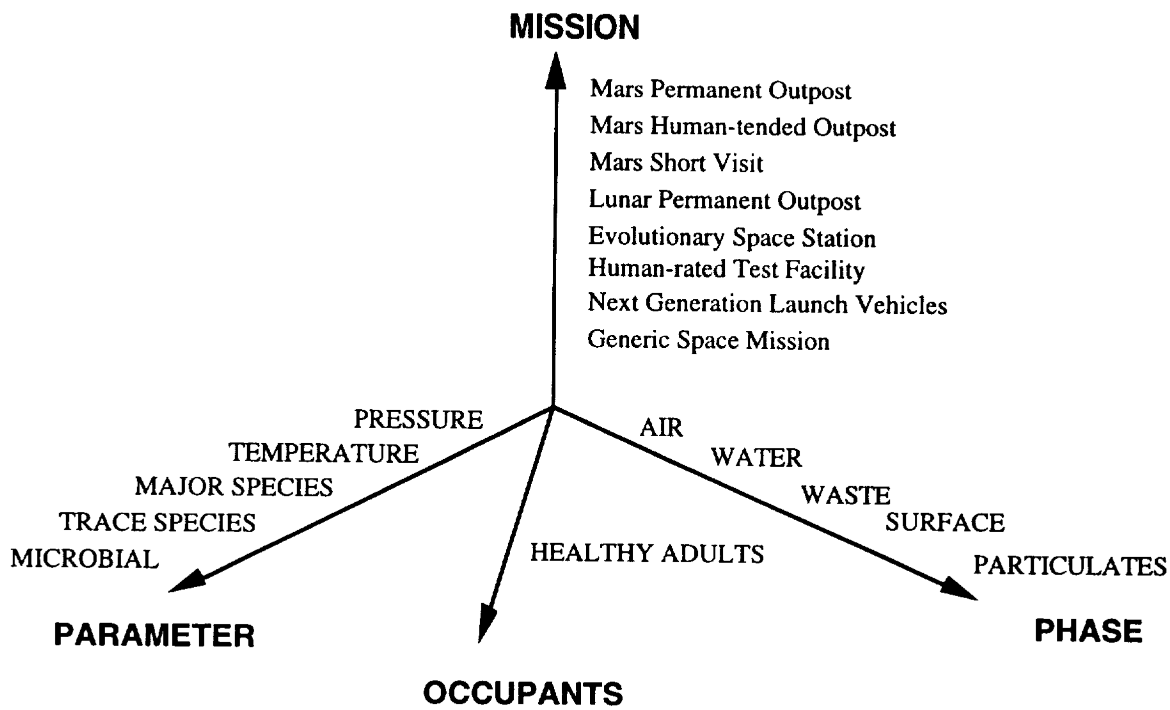

Figure 2. Organizaton of Environmental Monitoring and Controls Requirements.

3 MISSION SCENARIO OVERVIEW

The applicable mission scenarios are described below. Parameter tables corresponding to the mission scenarios are given in Appendix A.

3.1 Generic Space Mission

A generic space mission involves a specified number of crew as well as duration of mission, but does not have a specific destination such as the Moon or Mars. Consideration of the generic mission helps focus attention on the crew size, duration, and absence of gravity effects on the environmental monitoring requirements and leaves out all other factors. It is also assumed that none of the female crew is pregnant, and that one of the crew is a chemical payloads expert.

3.2 Next Generation Launch Vehicles

Launch vehicles beyond the current space shuttle will be the subject of interest under this mission category.

3.3 The Evolutionary Space Station

The evolutionary path for the currently planned space station is expected to lead to the autonomous operation of many systems on board including environmental monitoring and control system. The monitoring and control hardware would be light and require much less power. Most of the monitoring and control hardware targeted for the moon and Mars missions would be tested in this outer space facility. Crew size could be as high as 30 but none of the crew members may remain continuously on board for more than 3 months. This will be a permanent outpost in orbit around the earth subject to conditions of microgravity, space radiation, and extremely low temperatures.

3.4 Lunar Human-Tended Outpost

Utilizing an expendable transportation system, this mission would carry a crew of up to 6 for exploration activities on the surface of the moon for up to 30 days. The crew and outpost would be delivered separately. When the crew leaves, the outpost would be shut down and buttoned up. An average of 1 extravehicular activity (EVA) consisting of 2 crew members for a period of 8 hours would be part of the exploration mission. The earth-moon transfer vehicle will be capable of sustaining the crew for seven days. Environmental temperature, radiation, *etc.*, would depend on the choice of the site for the outpost. With no atmosphere, radiation levels are expected to be quite high requiring radiation monitoring and protective measures.

3.5 Lunar Permanent Outpost

A permanent lunar habitat would be established capable of supporting human life for extended periods of time. A crew of 30 would occupy the outpost and will exchange crew and receive resupplies every 180 days. However, crew could be sustained at the outpost without resupply for up to one year. Reusable transfer vehicles would be used with the Lunar Transfer Vehicle stationed at the low-earth orbit (LEO) Space Station and the Lunar Lander on the lunar surface. Pressurized rovers capable of carrying two crew members within a 100 km radius will support as needed the almost daily EVA outside the outpost. The same environmental conditions as before would apply.

3.6 Mars Short Visit

This will be a historic precursor human mission before establishing any kind of outpost on Mars. A crew of four will travel to Mars for over a year, land and explore the surface in EVA suits/rovers for up to 30 days. While on the surface of Mars, the Mars transit vehicle would be made to orbit Mars waiting to rendezvous with the crew at the end of the 30-day surface exploration. Mars has a thin atmosphere of predominantly carbon dioxide and has a diurnal period similar to Earth.

3.7 Mars Human-Tended Outpost

This mission is based on a three-year transit for the round trip to Mars in addition to 90 day surface stay for six crew members. Two crew members engaging in one EVA/day for eight hours and during transit one EVA is planned every 30 days. This mission will leave behind on Mars a reusable human outpost.

3.8 Mars Permanent Outpost

The permanent outpost on Mars would be capable of sustaining a crew of 12 for 600 days with pairs of crew members engaging in one EVA/day on the surface and one EVA every 30 days during the three-year transit.

4 ENVIRONMENTAL MONITORING AND CONTROL SYSTEM REQUIREMENTS

4.1 Environmental Monitoring System Schematic

Figure 3 shows a contextual schematic of an environmental monitoring and control system (EMCS) for spacecraft cabins. The cabin is monitored by a variety of miniaturized sensors and instruments (identified by the letter "S" in Figure 1) which communicate their measurements to EMCS through a digital bus implemented according to the recently adopted Fieldbus standard. There are other sensors monitoring the quality and quantity of storage of various life sustaining substances such as oxygen, water, food *etc.* as well as the quality and quantity of storage of waste substances generated in the cabin. These other sensors also report their measurements to EMCS using the digital bus. The control signals generated will be of three kinds:

(a) sensor querying and environmental actuator control during normal operations
(b) emergency override control of cabin environment including crew advisory
(c) life support supervisory control

The same digital bus is used to transmit control signals to actuators and subordinate controllers as well as to the human crew interface manager. Sensor input to the environmental monitoring and control system is also internally passed on to the inventory and maintenance management and scheduling system. In addition, the environmental emergency override management system will either receive computed rate data from time-stamped sensor measurements, or will compute the same using sensors measurements passed to it. Other systems such as fire suppression, emergency evacuation, *etc.* are also part of EMCS but have not been shown here.

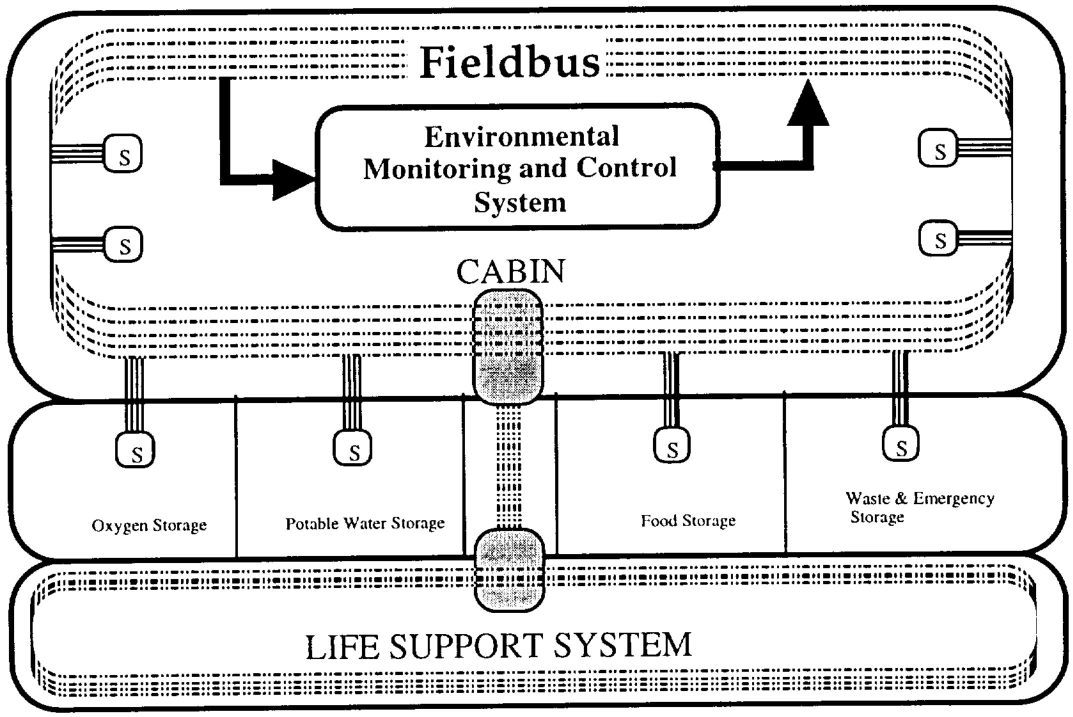

Figure 3 - Contextual Diagram. Fieldbus Sensors have Local Intelligence.

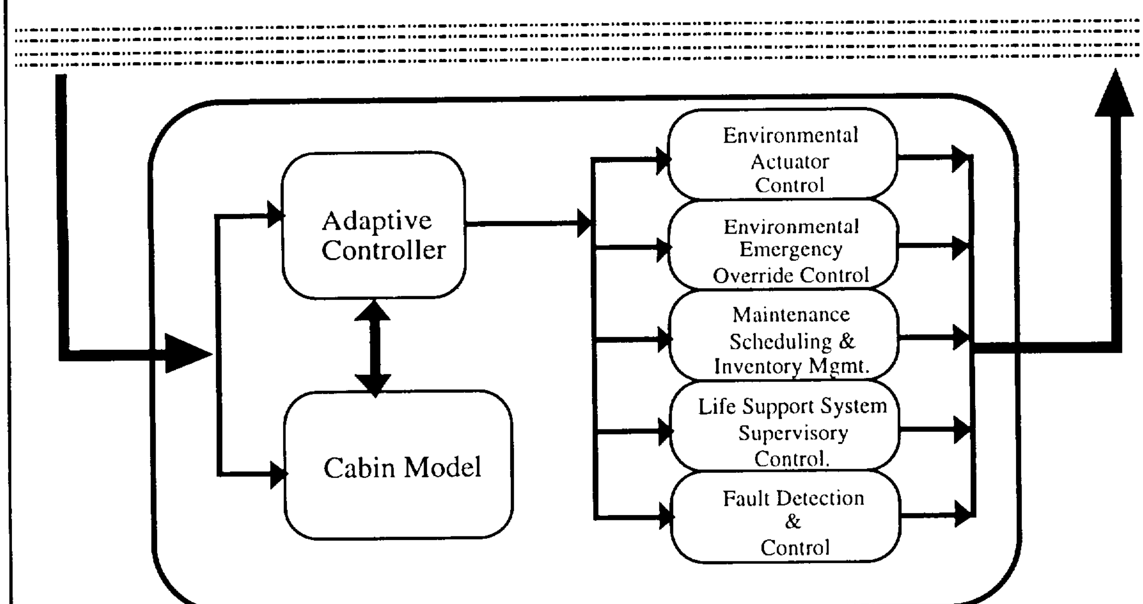

Figure 4 - Environmental Monitoring and Control System.

Figure 4 shows a schematic diagram of an adaptive and predictive model-based controller for the EMCS. In the interest of efficiency and cost control in controller validation, the controller is designed to benefit from a validated model of operation of the crew cabin. The model could be a simple fault tree-type, a sophisticated AI reasoning model, or a combined first-principle/AI model. These models allow for the inclusion of predictive modes into the control action, and give improved regulatory response. Model and data also allow for the detection and diagnosis of unexpected faults that can require emergency action or a reconfiguration of the control system.

Interactivity of environmental monitoring and control systems with advanced life support systems is anticipated and left for future versions of this document.

4.2 Systems Environmental Monitoring Functional Requirements

The environmental monitoring system monitors the cabin environment to which the human crew is exposed. The system must report both the time-stamped discrete measurements as well as their rates of change with respect to time. The measurements will be carried out by sensors/monitoring instruments connected to a local area network. Air, water, and surfaces must be monitored systematically. Also storage of fresh oxygen, makeup nitrogen, potable water, *etc.* must be monitored for quality and quantity. High-risk chemical experiments, waste storage containers, and storage areas shall be monitored for leakage.

4.3 Systems Environmental Control Functional Requirements

The EMCS shall include a centralized controller capable of unifying the measurements of an appropriate number of sensors and instruments into an assessment of the quality of the environment and the direction of improvement or deterioration of that quality. Sensor data fusion and trend prediction and control signal generation are the essential functions of the EMCS controller. The controller must operate in three modes, individually or simultaneously, as needed. They are the normal operating mode, the emergency response mode, and inventory management mode.

4.3.1 Normal Operations

During normal operations, the EMCS controller must respond to fluctuations in the temperature, pressure, humidity, concentrations of major and trace constituents in air and water. The response will be in the form of controlling the flow of fresh oxygen, make-up nitrogen, or water vapor into the cabin. When levels of major and minor constituents in air/water rise abruptly or unexpectedly, the controller sends a high-level control command to the life support system controller to rectify the deterioration in air/water quality.

4.3.2 Emergency Management

If environmental conditions deteriorate rapidly towards jeopardizing the health and survival of the crew, the EMCS controller shall switch to an emergency mode and take immediate, prescribed actions to protect the life and health of the crew.

4.3.3 Inventory Management

The EMCS controller keeps track of the total inventory of oxygen, nitrogen, and potable water within the habitat, and their availability at any time. Depending on need, the inventory manager shall allocate and move the supplies within its jurisdiction to various parts of the habitat. The inventory manager will also generate advisory messages to the crew and the life support system controller. It will maintain an active log of orders for resupplies and communicate them to the logistic operations in a timely manner.

5 AIR MONITORING REQUIREMENTS

5.1 Air Species and Particulates Monitoring Functional Requirements

Ambient air in the cabin must be monitored at selected locations, every 15 seconds, for the species O_2, CO_2, and CO. Sensors/instruments must be distributed throughout the cabin space, especially in areas where air is relatively stagnant. The comfort level of air must be reported in terms of temperature, pressure, humidity and oxygen content. *Toxicity of air must be reported in terms of specific major and trace species concentrations and their rates of rise.* The quantity of fresh oxygen and makeup nitrogen in storage must be periodically measured and reported. Particulate (dust) size-and-concentration, and microbial counts in air must be monitored and reported at regular intervals. Any critical or catastrophic deterioration in air quality must be immediately reported along with location information.

5.2 Air Species Quality Control Functional Requirements

The air quality controller shall receive reports of properties of ambient air from sensors and measuring instruments and compare them with the normal range and take action upon significant deviation from the normal. For example, if the carbon dioxide concentration in air rises monotonically, the controller shall send a high-level control command to the life support system to increase the rate of removal of carbon dioxide. If the life support system fails to respond or is unable to correct the problem, the air quality controller must divert a calculated flow of air to LiOH or other carbon dioxide scrubbing units. If unable to accomplish such scrubbing, the air quality controller will sound an alarm and instruct the crew to move to a less toxic region or suit up. Similarly, if a toxic trace contaminant buildup, or a dust buildup, is recognized, the air quality controller will attempt to identify, *via* rapid comparison to a comprehensive database, the source of the contaminant or dust and take the appropriate normal or emergency action.

In addition, the air quality controller must validate the measurements reported by each of the sensors and instruments and follow a protocol of checking and calibrating all air-monitoring sensors and instruments.

5.3 Requirements for Airborne Monitoring of Major Species, Trace Species, and Particulates in Habitats

Major sources of contaminants in the spacecraft include off-gassing of cabin materials and hardware, use of utility chemicals, and metabolic waste products of crew members. Minor sources of contaminants include electrical equipment, microbial metabolism, leakage during tests involving chemicals, leakage from environmental or flight control systems, volatile food components, volatile components of personal hygiene articles, and reaction products from the environmental control and life support system.

In response to NASA's request to establish guidelines for developing SMACs and to review SMAC documents for selected spacecraft contaminants, the Committee on Toxicology (COT) organized the Subcommittee on Guidelines for Developing Spacecraft Maximum Allowable Concentrations (SMACs) for Space Station Contaminants. The committee consists of experts in toxicology, epidemiology, medicine, physiology, biochemistry, pathology, pharmacology, neurotoxicology, industrial hygiene, statistics, and risk assessment. In the first stage of the study, the subcommittee prepared Guidelines for Developing Spacecraft Maximum Allowable Concentrations for Space Station Contaminants (NRC, 1992).

SMACs provide guidance on chemical exposures during normal as well as emergency operations aboard spacecraft. Short-term SMACs refer to concentrations of airborne substances such as a gas and vapor that will not compromise the performance of specific tasks by astronauts during emergency conditions or cause serious or permanent toxic effects. Such exposures might cause reversible effects such as mild skin or eye irritation, but they are not expected to impair judgment or interfere with proper responses to emergencies. Long-term SMACs are intended to avoid adverse health effects (either immediate or delayed) and to prevent decremental change in crew performance under continuous exposure to chemicals in the closed environment of the space station for as long as 180 days.

The sources of data for developing the SMACs are (1) chemical-physical characterization of the potential toxicant, (2) animal toxicity studies, (3) human clinical studies, (4) accidental human exposures, (5) epidemiological studies, and in some cases, (6) *in-vitro* toxicity studies. Ideally, dose-response data from human exposures are most desirable and should be used whenever possible. However, ethical concerns limit these studies to pollutants that are anticipated to have no residual effects. Classic toxicity studies employ animals from which models somewhat applicable to humans can be developed. When the model is carefully selected, animal studies give insight to the (1) most sensitive target organ(s), (2) nature of the effect on the target organs, (3) data for dose-response relationships, and (4) cumulative effects, if any, such as neurotoxicity and cancer, *etc.* In the absence of human dose-response data, animal studies fill a void; however, proper safety limits may need to be applied to the animal data.

Listed below are requirements for airborne monitoring of chemical species and particulates in habitats. These requirements have been reviewed by the air revitalization and toxicology groups at the Johnson Space Center (JSC) and Marshall Space Flight Center (MSFC). The recommendations may be changed as new knowledge is acquired, so that one should take care to look for the latest update of these criteria and SMACs.

5.3.1 Airborne contaminants and major components shall be monitored in sufficient detail and with a frequency that ensures that crew health, performance, and comfort will not be adversely affected by exposures to chemical vapors, gases, or particles.

5.3.2 Major air components shall be monitored on a near-continuous basis in the habitat atmosphere.

5.3.2.1 Oxygen concentration shall be monitored continuously at multiple locations within a range of 5-40%, and with an accuracy of $\pm$ 0.5%. At least one of the monitors shall be portable to facilitate analysis in confined spaces such as newly-arrived modules that are being opened after a long period of being sealed.

5.3.2.2 Carbon dioxide, which is likely to be a fire extinguishant, could be released suddenly in relatively high concentrations. The concentration of CO_2 shall be monitored in each modular segment on a near-continuous basis in concentration ranges from 0.3-20 torr with an accuracy of $\pm$ 0.3 torr.

5.3.2.3 Methane and hydrogen are not a toxicity threat. However they have explosive potential and can accumulate to very high levels in sealed environments. CH_4 and H_2 shall be monitored periodically at one location over the range 50-5000 ppm, and 40-4000 ppm, respectively.

5.3.3 A broad-spectrum analysis of trace airborne contaminants (35 or more targeted species) shall be performed at a sampling frequency compatible with ordinary fluctuations in the atmosphere. Generally, this will be from one day to one week, although monitoring may be needed more frequently when new modules are opened or when crew changeouts occur. Specificity and sensitivity of the analytical method shall be sufficient to facilitate calculation of toxicity indices (*T*-values) for each toxicity category (*e.g.*, irritants, hematotoxicants). There must be a capability to acquire samples in various locations in the habitat.

5.3.3.1 The list of seven targeted major components of interest to the Environmental Control Life Support Systems (ECLSS) Team is listed in Table I. The list of trace contaminants for monitoring by the Crew Health Care Systems (CHeCS) Team is derived mostly from those contaminants seen often above trace concentrations in Shuttle or Mir air. These species are also given in Table I. The monitoring method shall identify and quantify 95% of these primary trace contaminants. Listed in Table II are secondary contaminants which have been reported occasionally in Shuttle and Mir atmospheres. The monitoring method shall be capable of identifying and quantifying 90% of the compounds listed. Table III lists tertiary contaminants that are seen only rarely in space environments. The monitoring method shall be capable of identifying and quantifying 80% of the compounds of this list.

5.3.3.2 General quantification limits for contingencies and missions up to 600 days can be estimated from official SMACs in JSC 20584 as follows:

The upper quantification limit (UQL) method shall be twice the 1-hour SMAC if available, or 10 times the 7-day SMAC if no 1-hour SMAC is available.

The lower quantification limit (LQL) shall be 1/20th the 180-day SMAC if available, or 1/50th the 7-day SMAC if no 180-day SMAC is available. In no case does the quantification limit need to be below 5 ppb.

5.3.3.3 Because estimates of health effects from exposures to chemical mixtures are not precise, the analytical accuracy required is not extremely high. As a general guide the following accuracies are required:

$\pm$ 50% if the measurement is in the range: LQL to 10 x LQL
$\pm$ 30% if the measurement is in the range: 10 x LQL to 0.1 x UQL
$\pm$ 20% if the measurement is in the range: 0.1 x UQL to UQL.

5.3.4 Habitats located on extraterrestrial surfaces shall have the capability to monitor the airborne particulates according to size and concentration. Monitoring of particulate chemical activity may be performed as necessary.

Table I. Primary target compounds for monitoring, with 180-day SMACs (in parenthesis)

major species (ECLSS Team)

hydrogen (4100 ppm)	carbon monoxide (10 ppm)
methane (5300 ppm)	oxygen (---)
water (---)	carbon dioxide (7000 ppm)
nitrogen (---)	

trace species (CHeCS Team)

acetaldehyde (2 ppm)	acetone (22 ppm)
acrolein (0.015 ppm)	1-butanol (12 ppm)
benzene (0.07 ppm)	ethanol (1000 ppm)
1,2-dichloroethane (0.2 ppm)	*octamethylcyclotrisiloxane (n/a)
ethyl acetate (no SMAC)	4-methyl-2-pentanone (35 ppm)
formaldehyde (0.04 ppm)	2-propanol (60 ppm)
methanol (7 ppm)	trimethylsilanol (10 ppm)
methyl ethyl ketone (10 ppm)	vinyl chloride (1 ppm)
dichloromethane (3 ppm)	ethyl benzene (30 ppm)
toluene (16 ppm)	carbon disulfide (n/a)
xylenes (50 ppm)	furan (n/a)
diacetone alcohol (4 ppm)	limonene (n/a)
benzaldehyde (n/a)	isoprene (n/a)
2-butoxyethanol (n/a)	*1,1,1-trichloroethane (n/a)
*Freon 11 (n/a)	chloroform (n/a)
*Freon 12 (n/a)	*C_3 - C_8 saturated aliphatic aldehydes (n/a)
*Freon 22 (n/a)	C_5 - C_7 alkanes (n/a)
Freon 113 (50 ppm)	*acetic acid (n/a)
*perfluoropropane (Freon 218) (n/a)	carbonyl sulfide (n/a)

* 180-day SMACs should be available in September 1996.

Table II. Secondary target compounds for monitoring, with 180-day SMACs (in parenthesis)

indole (0.05 ppm)	ammonia (10 ppm)
ethylene glycol (5 ppm)	others (TBD)

Table III. Tertiary target compounds for monitoring, with 180-day SMACs (in parenthesis)

[TBD]

5.3.4.1 The health effects of respirable and nonrespirable particles differ, hence particle measurements shall be separated into fractions having sizes less than 10 μm, and those larger than 10 μm in aerodynamic diameter.

5.3.4.2 The limits of particle exposure will depend on the respirability and chemical composition of the particles involved. The chemical reactivity could vary greatly depending on the source (*e.g.*, Lunar dust *vs.* Martian dust). As a general guide, the mass of particles in the respirable range (< 10 μm diameter) shall be quantified to 0.01-10 mg/m^3, to an accuracy of ±20%.

5.3.5 A capability shall be provided to rapidly detect marker chemicals which could suddenly be released into the cabin atmosphere as a result of overheating of electronics. This capability shall include the ability to follow the progress of decontamination of the air after the event occurs (see also Sec. 5.3.7).

5.3.5.1 Monitors shall be capable of rapidly responding (< 15 sec) to the pyrolysis markers CO, HCN, and HCl if present in the cabin air at concentrations that could threaten crew health. The monitors should issue a warning if the concentration reaches the 7-day SMAC, and an alarm if the concentration reaches the 1-hour SMAC.

5.3.5.2 The analytical range of the monitors shall be as follows:

analyte	**range**	**accuracy**
CO	1-500 ppm	1 ppm
HCN	0.1-50 ppm	0.1 ppm
HCl	0.1-50 ppm	0.2 ppm

CO will be the primary compound for measurement. However, a secondary requirement for HCN and HCl also exists.

5.3.6 A capability shall be provided to specifically monitor hazardous chemicals that could suddenly be released from fluids systems, payload experiments, extravehicular activity, or waste storage. Monitoring shall be localized to the area where the release could occur, and be rapid so that any release from the source does not reach the general atmosphere. The specifics of this requirement cannot be defined until high-risk chemical usage is better defined.

5.3.7 A computer model shall be available to predict the behavior of specific contaminants and the contamination removal capabilities for contaminants that could be suddenly released into the atmosphere. The model must be experimentally verified, and be capable of *spatial* resolution to the module level, and *temporal* resolution to 0.5 hour. The model predictions shall be accurate to within ±30% for chemicals that pose a toxicity risk. Possible candidates for the list include: carbon dioxide, ammonia, ethylene glycol, formaldehyde, and glutaraldehyde. This list will be expanded for habitats that involve plant growth, and possible disposal by incineration.

References:

Johnson Space Center Document JSC 20584 (Johnson Space Center, Houston, TX 77058)

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NRC 1984b, "Emergency and Continuous Exposure Limits for Selected Airborne Contaminants," Vol 2., Washington, D.C., National Academy Press.

NRC 1984c, "Emergency and Continuous Exposure Limits for Selected Airborne Contaminants," Vol 3., Washington, D.C., National Academy Press.

NRC 1992, "Guidelines for Developing Spacecraft Maximum Allowable Concentrations for Space Station Contaminants," Washington, D.C., National Academy Press.

6 WATER MONITORING REQUIREMENTS

6.1 Water Species Monitoring Functional Requirements

All water, potable, hygiene, or otherwise which can be contacted by the human crew must be under surveillance, at frequencies of measurement which are discussed below, with the use of on-line sensors and off-line monitoring instruments. Inorganic, organic, and microbiological pollutants in water along with several additional physical parameters (i.e. pH, TOC, conductivity, turbidity, and dissolved gases), must be regularly measured and reported to the EMCS controller. Sensors and instruments must be positioned in the water storage tanks (where critical) as well as close to the point of delivery in the cabin. Off-line monitors must have the capability to accept samples collected through a "lock and load" mechanism; this approach to sample handling will facilitate the analysis process and minimize human contact with potentially harmful materials.

A preliminary list of requirements for water quality monitoring is given in Appendix B. A Draft Joint U.S./Russian International Space Station Specification for potable and hygiene water is also provided. The MCLs for each parameter are based in part on current U. S. Environmental Protection Agency (EPA) guidelines for drinking water. *However, it is recommended that each MCL be reviewed by a panel of toxicologists and drinking water specialists so that monitoring priority and frequency are properly defined for each parameter on the basis of toxicity and other key factors.* Spacecraft water system specific historical data (whether a species has been detected previously in spacecraft reclaimed water) should also be considered in assessing monitoring priority.

The outline that follows is intended to be a guideline to direct water quality sensor research and development:

1. Basic water quality parameters such as conductivity, total organic carbon (TOC), pH, turbidity, free and dissolved gas, color, dissolved solids, and biocide concentration (e.g. iodine or silver) should be frequently monitored using on-line or continuous sensors.

2. A weakness of the current technology and practice of water reclamation (multifiltration) is the inefficient removal of volatile organic compounds such as alcohols and ketones from waste streams. Thus, a means to detect specific volatile organic compounds in water is needed.

3. Sensors for ammonia and urea, which can be considered indicator species of waste water, are needed.

4. Rapid, specific sensors for transition metals such as aluminum, cadmium, lead, selenium, and chromium are needed.

5. An electrode-based chemical oxygen demand sensor should be investigated as an equivalent or alternative to TOC.

6.2 Water Species Quality Control Functional Requirements

The water quality controller shall receive measurements of impurities in water, such as acidity, alkalinity, total organic carbon, toxic metal ions, microbial count, *etc.* and compare these levels with the acceptable standard. Upon recognizing a monotonically rising level of toxicity or pathogenicity in water, the water quality controller will shut off human access to the polluted water and send an advisory to the crew as well as to the life support system controller. If a quantity of water is excessively polluted by a catastrophic event such as spillage of toxins into water streams or storage, the water quality controller must move the polluted water mass to isolated or segregated storage for eventual reclamation or venting off.

In addition, the water quality controller must validate the measurements reported by each of the sensors and instruments and follow a protocol of checking and calibrating the sensors/instruments and generating service requests with respect to all sensors/instruments pertaining to water monitoring.

6.3 Water Contaminants

For each of the water-borne contaminants, chemical or microbiological, only one exposure limit has been found in the literature without regard to duration of exposure. These limits are referred to as SMCLs (or MCLs). Nevertheless, it is possible to identify human physiological mechanisms through which water-borne toxins could be accumulated in the body and manifest their toxic effects upon reaching or exceeding a certain level of accumulation. However, such data have not been readily available for inclusion here. Therefore, conservatively, all exposure limits listed in the Appendix tables shall be construed as applying without regard to mission duration.

7 WASTE MONITORING REQUIREMENTS

7.1 Waste Species Monitoring Functional Requirements for Air

Sensors and/or monitoring instruments must be positioned strategically around storage of carbon dioxide, methane, *etc.* which are part of the life support system. In addition, sensors must be located upstream of non-return valves. Also, gas monitoring devices must be positioned around storage of aqueous and nonaqueous wastes and solid wastes and any sudden rise in toxic pollutant concentration shall be reported to the air quality controller along with location information.

7.2 Waste Species Monitoring Functional Requirements for Water

Sensors and monitoring instruments must be positioned inside waste water storage containers as well as all streams connecting to waste storage tanks. Leaks of aqueous and nonaqueous fluids into habitat space, floor and walls must be measured by appropriate sensors/instruments. These sensors supplement normal water quality sensors in that they are specific to the type of pollutants found largely in waste water streams, and would cover a significantly different concentration range. It is not known if the desired aqueous phase waste species sensor technology is currently available.

7.3 Waste Species Control and Containment Functional Requirements

When a toxic leak has been detected and its location identified, the EMCS controller must attempt to divert the waste stream to a nonleaking channel, if available, thus isolating the leaking section. If a storage tank is leaking the controller will attempt to transfer the contents to a secure tank and isolate the leaky tank for repairs. After preventing further leak, the controller must initiate local emergency clean-up measures and restore the quality of the cabin/habitat.

8 SURFACE MONITORING REQUIREMENTS

8.1 Surface Species Monitoring/Control Functional Requirements

With the help of a crew member or a robotic scanner, all moist surfaces such as in the kitchen, toilets, and showers must be scanned with the help of ultraviolet light or other means to identify microbial contamination. These contaminations must be identified *in situ* or through culture. Further examination can be done employing wipe tests, for which wipes are analyzed for the presence of microbes or their byproducts. When pathogenic colonies have been identified, the affected area must be quarantined and sterilization/neutralization procedures initiated.

Non-microbial contamination of surfaces may be a concern in some mission scenarios. Surface monitoring requirements may be developed on an *ad hoc* basis.

8.2 Surface Contaminants

Monitoring of surface contaminants is presumed to be essentially for microbial populations. However, it is possible to conceive of chemical contamination especially in the context of accidents/spills of chemicals brought on board with payloads for experiments in space. Again, the allowable levels of bacteria, fungi, viruses *etc.*, shown in Appendix C apply to all missions without regard to duration.

9 MICROBIAL CONTAMINATION

A preliminary list of microbial contamination requirements as documented for Space Station is presented in Appendix D. It should be emphasized that the technology for microbial measurements is rapidly changing, and new methods based on molecular biology are being developed. *It is recommended that this topic be revisited in the near future by a panel consisting of personnel from microbiology, regulatory, and medical* *disciplines*. The present outline is intended to provide some guidelines which would be re-assessed by a future working group. These guidelines are as follows:

1. Newer methods, other than those based on direct assays, are on the horizon, and should be considered for establishing the requirements.

2. Potential hazards should be discussed. These include infectious diseases, allergies, and biodegradation of materials. Biodegradation can compromise the integrity of different elements such as rubber seals, *etc*.

3. The list of microorganisms should be expanded to include biofilm forming species, plant pathogens, and opportunistic pathogens. The list should also be grouped and prioritized with respect to pathogenicity, and other criteria.

4. Speciation of fungi should be made.

5. The list of microorganisms for air and water should be more exhaustive.

6. The panel felt that the frequency of microbial monitoring should be once in two days. The panel was conscious of the fact the measurement must not put additional workload on the crew. New technologies should be applied for such monitoring. Moreover, if a pathogenic microbial contaminant is detected, then the measurement frequency should be increased. Instrument response time of approximately 2 hours after collection is a good goal for future technology development. Present methods take days. The long-term goal may be set at monitoring the bioparticles on a continuous basis.

7. Sampling locations must be redefined for each mission, and amended during the mission as needed. Locations such as air conditioner ducts are more likely places for microbial presence.

8. Measurement units must be cells or virions per unit area or unit volume. Listing detection requirements in colony-forming units (CFUs) should not limit the application to technologies that measure CFUs directly. Methods that measure biologically synthesized macromolecules and correlate those values to CFUs are acceptable.

   A surprisingly wide range of accuracy may be acceptable under the current state of the art, depending also on the method of measurement. A measurement accuracy of 20% - 500% for methods based on macromolecule concentration in the microbe is acceptable. The large range in the accuracy arises from the fact that macromolecule concentration/CFU ratios can vary significantly among bacterial species and among bacterial populations. The method based on the characterization of macromolecules is sensitive for microbial detection. However, relating the results to the bacterial concentration has a wide variation because of the variation in the concentration of the macromolecules in the microorganism with different species, and maturity of the population.

9. Absolute lower detection limit of five cells for bacteria from any source is desirable. Such detection limits are achievable in a near term, given a reasonable development in technology.

10. Virus detection in air and on surfaces should have very stringent limits. Generally, viruses are not present in the space environment, although some latent viruses may be present. There should be no virus in the crew environment. Monitoring instruments capable of detecting the presence of single virion in the environment should be available and considered for use in the near future. However, single virion detection may not be critical since an infected crew member will shed quantities of virus. A strict quarantine for the crew should be enforced. Other experts should be consulted for further defining the virus contamination requirements.

11. The viability of detected microbes needs to be assessed. Viability determination, besides being made by direct-assay methods, also can be made by monitoring the increase in cell counts with time.

The following list of organisms is proposed for spacecraft water quality monitor assay activity. The list is hierarchical, so that if there are no bacteria present, subsequent assays for specific bacterial taxons are unnecessary.

<u>Microorganism or Virus</u>

1. Any Bacteria
2. Any Fungi
3. Legionella sp.
4. Enteric Bacteria
5. Gram Positive Bacteria
6. Pseudomonas aeruginosa
7. Pseudomonas sp.
8. Mycoplasma sp.
9. Acinetobacter sp.
10. Listeria sp.
11. Thiobacillus sp.
12. Cryptosporidium
13. Candida albicans
14. Cryptococcus sp.
15. Burkholderia sp.
16. Histoplasma sp.
17. Norwalk Virus
18. Hepatitis A Virus
19. Rotavirus

10 PLANTS EXPOSURE SPECIFICATIONS

[TBD]

11 SENSOR/INSTRUMENT CHARACTERISTICS AND PARAMETER-MONITORING REQUIREMENTS

Parameter-monitoring is directed at specific physical properties such as temperature, pressure, presence and concentration of specific chemical, microbiological, and particulate constituents. Instrument requirements are organized into three categories, *viz.*, performance requirements, mass requirements, and environmental tolerance requirements. Under each category there are specific parameters. The basis for deriving a mission-driven specification for each of them is given in the following sections:

11.1 Performance Requirements

11.1.1 Measurement Range

A sensor/instrument is expected to generate an output that monotonically rises over the required input range specified. The measurement range is specified in terms of upper and lower limits of input. These are derived from exposure-limit or comfort-level data.

11.1.2 Sensitivity

The sensitivity of a sensor/instrument is the slope of the input-output response curve. The higher the slope, the more sensitive or responsive is the sensor/instrument. However, it is not the deadband which is the input range over which there is no change in output. For example, the sensitivity of a pressure sensor could be expressed as mV/kPa. However, a number such as 0.1mV/kPa does not, by itself, convey the magnitude of the sensitivity or its desirability. Instead, the ratio of instrument output at the upper limit of the measurement range over that at the lower limit will provide a dimensionless magnitude of the response of the instrument to change in input over the measurement range. In this document, sensitivity is defined as such a ratio.

11.1.3 Selectivity

For a sensor/instrument which generates an output in response to more than one input parameter, selectivity is defined as the ratio of the response of the instrument to one unit of the preferred input parameter to one unit of the competing input parameter. For example, selectivity of a carbon dioxide sensor in the presence of humidity will be defined as the ratio of sensor output to 1kPa of carbon dioxide partial pressure in the absence of humidity and to 1kPa of water vapor in the absence of carbon dioxide. The concept of selectivity does not apply to spectrometric instruments which separate output signals into distinguishable features for each of the input parameters.

11.1.4 Instrument Resolution

The resolution of an instrument refers to the smallest interval between two adjacent discrete details which can be distinguished one from the other. For example, a resolution of 2 atomic mass units (amu) for a mass spectrometer is insufficient to distinguish between ammonia (17 amu) and water vapor (18 amu). Analogous criteria exist for the chemical surface-resistance arrays (separation between the occupied volumes of phase space of the principle components), photon-absorption methods (the laser linewidth/spectrometer bandpass), *etc.*

11.1.5 Response Time

The response time is the time required for an output to change from an initial value to a specified percentage of the final steady-state value, either before or in the absence of overshoot, as a result of a step change to the input. When the percentage specified is 1-1/e = 63.2%, the response time is also known as the time constant of the instrument. It is necessary that the time constant of a monitoring instrument be smaller than the time constant of the component or system monitored. For example, if it is given that 55 ppm of carbon monoxide would induce toxic symptoms in human beings in about 60 minutes, the time constant for a carbon monoxide monitor should be much less than 60 minutes for atmospheres in which carbon monoxide concentrations will not significantly exceed 55 ppm. If, for instance, the carbon monoxide concentration could quickly go as high as 550 ppm before corrective action could be taken, the time constant or response time of the monitor would have to be far less than the human toxic response to that concentration. The requirements for response time or time constant for various monitored parameters will depend on the human toxic response time or the time constant for the cleanup process unit, whichever is less. In this document, time constants to be required for toxic contaminant monitors are one hundredth the time taken for manifestation of toxic response. For process monitors, it will be one hundredth the time constant of the trace-contaminant removal process unit.

It is recognized that the response time for air, water, and microbial sensors may vary considerably, due to the current state of the technology and to different functional requirements. For example, the turbidity measurement for water can be very useful despite its lacking the linearity and accuracy of other types of measurements.

11.1.6 Sampling Frequency

Sampling frequency is defined as the number of samples per unit time to be drawn and analyzed by a sample-drawing instrument or the number of queries by a controller for measurements from a continuous or real-time measuring instrument. The required sampling frequency is the reciprocal of the required time constant of the measurement process where measurement process is defined as that between the initiation of sampling (or querying action) and the return of a measured value.

11.1.7 Linearity

Linearity is defined as the maximum deviation of the calibration curve (average of upscale and downscale readings) from a straight line connecting the upper and lower limit values on the calibration curve. Smaller deviations mean smaller errors in measurement and simpler controller design. In this document linearity requirements are nominally set to one-tenth of the lower limit of the measurement range.

11.1.8 Accuracy

Accuracy or accuracy rating of a sensor or measuring instrument is defined as the deviation between the measured value reported by the sensor/instrument and the actual input value. A stated accuracy includes combined effects conformity, hysteresis, deadband and repeatability errors. In this document accuracy requirements are expressed as a ±percent of actual output reading and is set at one half of the linearity requirement.

11.1.9 Drift

Drift is defined as an error in measurement manifesting over a long period of time. In this document, requirements for drift limit it to 1.5 times the linearity requirement.

11.2 Mass Requirements

Contributions to the system mass or launch mass necessitated by the integration of a sensor/monitoring instrument to the spacecraft are the parameters considered under this category. This document requires that all such contributions be kept to a minimum. The various contributions are listed below.

11.2.1 Sensor/Instrument Mass

11.2.2 Mass equivalent of electrical power demanded by the sensor/instrument. The multiplication factor varies with the type of power plant chosen for the mission such as photovoltaic, nuclear, *etc.*

11.2.3 Mass equivalent of cooling demand.
The multiplication factor varies with the type of cooling device such as thermoelectric, vapor compression, *etc.*

11.2.4 Mass of consumables.
This is a product of the daily rate of consumables supplied to the sensor/instrument and the mission duration in days.

11.2.5 Mass of redundant units.
Whenever the operating life of a sensor/instrument is significantly less than the mission duration, redundant sensors/instruments would be required. The statistical operating life estimate is typically referred to as MTBF (Mean Time Between Failures).

11.2.6 Mass of interface hardware.
This pertains to additional electrical, mechanical, and structural hardware required to connect and integrate a sensor/instrument with the rest of the system.

11.2.7 Crew servicing.
This pertains to additional mass to be provided to support the crew members who are required to service and maintain a sensor/monitoring instrument. Appropriate parameters are MTTR (Mean Time To Repair) and MTBM (Mean Time Between Maintenance). Crew service is expressed as total person-hours over the entire duration of a mission. The multiplication factor for conversion of person-hours to additional mass includes food, water and oxygen.

11.3 Environmental Tolerance Requirements

These requirements are derived from our knowledge of the mission environment. It is required that any sensor/monitoring instrument included for a mission operate satisfactorily under the environmental conditions of the mission. The various environmental parameters are:

11.3.1 Minimum cabin temperature and pressure
11.3.2 Maximum cabin temperature and pressure
11.3.3 Minimum external temperature and pressure
11.3.4 Maximum external temperature and pressure
11.3.5 Cabin off-gassing rates
11.3.5 Cabin low humidity
11.3.6 Cabin high humidity
11.3.7 External low humidity/corrosive concentration
11.3.8 External high humidity/corrosive concentration
11.3.9 Lift-off delta-g, transit-g, and surface-g
11.3.10 Electromagnetic interactions among equipment and sensors
11.3.11 Maximum external radiation

12 PARAMETER MONITORING REQUIREMENTS FOR AIR

The lower and upper limits of control for cabin temperature (18°C and 27°C) are specified on the basis of thermal comfort for the human body. The required lower and upper limits of measurement of cabin temperature will be reasonably below and above the respective control limits.

The upper and lower limits of control for atmospheric pressure are based on airlock operations for EVA (101 kPa and 29.5 kPa). The required lower and upper limits of ambient pressure measurement will be reasonably below and above the respective control limits.

Mission rules require oxygen masks whenever ambient oxygen partial pressure falls below 16 kPa. The lower limit of measurement of oxygen partial pressure will be reasonably below this critical lower limit. The upper limit will be reasonably above the normal partial pressure of oxygen at sea level on Earth of 21 kPa.

Partial pressure of water vapor in ambient air is specified on the basis of human comfort which is known to be around 1.3 kPa. The upper and lower limit of measurement of partial pressure of water vapor will be based on this number.

13 PARAMETER MONITORING REQUIREMENTS FOR WATER

The lower monitoring limit for each species and property is set at 10% of the SMCL and the upper limit at twice the SMCL.

The frequency of sampling for water analysis or *in situ* monitoring will depend upon the time constant of the appropriate water purification equipment. For microbial monitoring in water, the frequency of sampling will depend on the reproductive cycle time of the pathogen in the spacecraft environment. However, the reproductive cycle time with extremely low and unknown levels of nutrients in water cannot be estimated satisfactorily. In this case the sampling frequency requirement should be guided by current practice, and the frequency should be doubled if microbial colonies are found in water samples.

14 PARAMETER MONITORING REQUIREMENTS FOR SURFACES

Current practice for monitoring surfaces inside the cabin is once per month and upon crew exchange. The procedure consists in the use of moistened swab or contact plate containing an agar medium to sample surfaces. In lieu of time-consuming routine sampling, surfaces must be cleaned regularly with diluted surfactant solutions. Selected surfaces associated with or in the proximity of waste receiving, processing and storage units must be disinfected with an environmentally-compatible disinfectant such as hydrogen peroxide. Microbial monitoring requirements will be revisited when technologies currently under development become available for rapid scanning, detection, and identification of microbial species.

APPENDICES

Appendix A:	**Planned Human Space Missions**
Appendix B:	**Physical Parameters** **Air Comfort Ranges** **Water SMCL Tables** **U.S./Russian ISS comparison**
Appendix C:	**Space Station Microbiology Requirements**
Appendix D:	**Proposed Technology Assessment Metric**

APPENDIX A

Planned Human Space Missions

ID	Description	Crew Size	Transit Duration, Days	Surface Stay Duration, Days	Number of Transit EVAs/30 Days	Duration of Transit EVAs, Person-days	Number of Surface EVAs/Day	Duration of Surface EVAs, Person-days
Generic Space Mission	?							
Next Generation Launch Vehicles	Extended Orbiter ?	4	21	0	0	20	0	0
Human-Rated Test Facility	NASA-JSC's Proving Ground for Environmental Monitoring/Control and Life Support Systems	4	0	90	0	0	0	0
Evolutionary Space Station	Beyond ISS, Version 1.0	10	3650	0	10	1200	0	0
Lunar Human-Tended Outpost	Short stay on the moon with long periods of nonoccupancy of the outpost	4	7	60	0	0	1	40
Lunar Permanent Outpost	Continuously operating outpost and longer crew durations between crew changes	30	7	365	0	0	3	480
Mars Short Visit	R/T to Mars with short stay on the surface	4	1100	7	1	8	1	4
Mars Human-Tended Outpost	Split-sprint type mission to Mars, set up outpost with long periods of nonoccupancy of the outpost	6	1100	90	1	8	1	50
Mars Permanent Outpost	Continuously operating outpost and longer crew durations between crew changes	12	1100	600	1	8	1	400

ID	Power Availability for EMCS, Upper Limit, W	Launch Mass for EMCS, Upper Limit, kg	Crew Time Availability for EMCS, Person-Hours/day	Minimum Cabin Temperature C	Maximum Cabin Temperature C	Minimum Cabin Pressure, Ambient - kPa	Maximum Cabin Pressure, Ambient - kPa
Generic Space Mission							
Next Generation Launch Vehicles	50	5	6	20	30	69	101
Human-Rated Test Facility	100	10	6	20	30	69	101
Evolutionary Space Station	200	20	6	20	30	69	101
Lunar Human-Tended Outpost	100	10	6	20	30	69	101
Lunar Permanent Outpost	200	20	12	20	30	69	101
Mars Short Visit	100	10	6	20	30	69	101
Mars Human-Tended Outpost	100	10	4	20	30	69	101
Mars Permanent Outpost	150	15	2	20	30	69	101

ID	Minimum External Temperature C	Maximum External Temperature, C	Minimum External Pressure, Ambient - kPa	Maximum External Pressure, Ambient - kPa	External Radiation Level, Maximum	g on EMCS - Operational Lower Limit	g on EMCS - Operational Upper Limit
Generic Space Mission							
Next Generation Launch Vehicles	-200	-100	0	0	0	0.001	20
Human-Rated Test Facility	20	30	101	101	0	1	1
Evolutionary Space Station	-200	-100	0	0	0	0.001	0.001
Lunar Human-Tended Outpost	-200	-100	0	0	0	0.001	0.17
Lunar Permanent Outpost	-200	-100	0	0	0	0.001	0.17
Mars Short Visit	-200	-100	0.65	0.75	0	0.001	0.38
Mars Human-Tended Outpost	-100	-20	0.65	0.75	0	0.001	0.38
Mars Permanent Outpost	-100	-20	0.65	0.75	0	0.001	0.38

APPENDIX B

Physical Parameters

Comfort Levels for Ambient Air

Parameters	Limit	Units
MISCELLANEOUS		
Low Temperature	18	C
High Temperature	27	C
Low Pressure	29.5	kPa
High Pressure	101.3	kPa
Humidity(Partial Pressure of Water Vapor)	1.3	kPa
Low Oxygen Partial Pressure	16	kPa
High Oxygen Partial Pressure	35	kPa
Particulates	1000	Count/m*3

References

1 Nicogossian et.al., Space Physiology and Medicine, 3rd Edn., Lee & Febiger, 1993

Spacecraft Maximum Contaminant Level (MCL) for Potable Water(3,5)

Compounds	MCL	Units
PHYSICAL		
Total Solids (Suspended/Dissolved)	100	mg/L
Color True	15	Pt/Co
Taste and Odor	3	TTN/TON
pH, min	6	
pH, max	8.5	
Particulates (maximum size)	40	microns
Turbidity	1	NTU
Dissolved Gas (Free @ 37 degrees C)	0.5	ml/(50 ml)
Free Gas (@STP)	0	mg/L

References

3 "Man-System Integration Standards" NASA-STD-3000 Vol. 1. Rev.A (1989)

5 "System Specification for the International Space Station Alpha," SSP 41000, 9 February 1994
contract no. NAS15-10000
Boeing Defense and Space Group
Space Station Program Office

Note: Total Hardness can be calculated from other inorganic parameters.

Spacecraft Maximum Contaminant Level (MCL) for Potable Water(5)

Compounds	MCL	Units	
INORGANIC CONSTITUENTS			
Ammonia	0.5	mg/L	
Arsenic	0.01	mg/L	
Barium	1	mg/L	
Cadmium	0.005	mg/L	
Calcium	30	mg/L	
Chlorine (Total)	200	mg/L	
Chromium	0.05	mg/L	
Copper	1	mg/L	
Cyanide	200	μg/L	ref (3)
Iodine (Total)	15	mg/L	
Iron	0.3	mg/L	
Lead	0.05	mg/L	
Manganese	0.05	mg/L	
Magnesium	50	mg/L	
Mercury	0.002	mg/L	
Nickel	0.05	mg/L	
Nitrate (NO_3-N)	10	mg/L	
Potassium	340	mg/L	
Selenium	0.01	mg/L	
Silver	0.05	mg/L	
Sulphate	250	mg/L	
Sulfide	0.05	mg/L	
Zinc	5	mg/L	

References

3 "Man-System Integration Standards" NASA-STD-3000 Vol. 1. Rev.A (1989)

5 "System Specification for the International Space Station Alpha," SSP 41000, 9 February 1994
contract no. NAS15-10000
Boeing Defense and Space Group
Space Station Program Office

Spacecraft Maximum Contaminant Level (MCL) for Potable Water(5)

Compounds	MCL	Units
BACTERICIDES		
Residual Iodine (minimum)	1	mg/L
Residual Iodine (maximum)	4	mg/L

References

3 "Man-System Integration Standards" NASA-STD-3000 Vol. 1. Rev.A (1989)

5 "System Specification for the International Space Station Alpha," SSP 41000, 9 February 1994
contract no. NAS15-10000
Boeing Defense and Space Group
Space Station Program Office

Spacecraft Maximum Contaminant Level (MCL) for Potable Water(3,5)

Compounds	MCL	Units
AESTHETICS		
Cations	30	mg/L
Anions	30	mg/L
CO_2	15	mg/L

References

3 "Man-System Integration Standards" NASA-STD-3000 Vol. 1. Rev.A (1989)

5 "System Specification for the International Space Station Alpha," SSP 41000, 9 February 1994
contract no. NAS15-10000
Boeing Defense and Space Group
Space Station Program Office

Spacecraft Maximum Contaminant Level (MCL) for Potable Water(5)

Compounds		MCL	Units
MICROBIAL			
Bacteria/ Fungi	Total Count(1,5/2,5)	100	CFU/100mL
Coliform	Total Count(3,5)	0	CFU/100mL
Viruses	Total Count(4)	0	CFU/100mL

References

5a FAX from Duane Pierson of JSC dated Aug 21, 95

Spacecraft Maximum Contaminant Level (MCL) for Potable Water(3)

Compounds	MCL	Units
MICROBIAL		
Bacteria		
Total Count	1	CFU/100mL
Anaerobes	1	CFU/100mL
Aerobes	1	CFU/100mL
Gram Positive	1	CFU/100mL
Gram Negative	1	CFU/100mL
E. Coli	1	CFU/100mL
Enteric	1	CFU/100mL
Viruses	1	CFU/100mL
Yeasts and Molds	1	CFU/100mL

References

3 "Man-System Integration Standards" NASA-STD-3000 Vol. 1. Rev.A (1989)

5 "System Specification for the International Space Station Alpha," SSP 41000, 9 February 1994
contract no. NAS15-10000
Boeing Defense and Space Group
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Detection Methods:
1 Incubation 48 Hrs. at 30C in Media R2A
2 Incubation 48 Hrs. at 30C in Media DG-18
3 Incubation 24 Hrs. at 35C in Media M-Endo
4 Tissue Culture Assay
5 Membration Filtration Method

Spacecraft Maximum Contaminant Level (MCL) for Potable Water(3)

Compounds	MCL	Units	
ORGANICS			
Total Acids	500	µg/L	
Cyanide	200	µg/L	
Halogenated Hydrocarbons	10	µg/L	
Phenols	1	µg/L	EPA is 4000 µg/L
Total Organic Carbon (TOC)	500	µg/L	
Uncharacterized TOC (UTOC)	100	µg/L	
Total Alcohols	500	µg/L	
Organic Constituents (4)			
Volatiles			
Benzene	5	µg/L	
Chlorobenzene	100	µg/L	
1,2-dichlorobenzene	600	µg/L	
1,4-dichlorobenzene	75	µg/L	
Toluene	2000	µg/L	
Ethylbenzene	700	µg/L	
Carbontetrachloride	5	µg/L	
1,1-dichloroethane	7	µg/L	
1,2-dichloroethane	5	µg/L	
1,1,1-trichloroethane	200	µg/L	
Trichloroethane	5	µg/L	
trans-1,2-dichloroethane	100	µg/L	
Tetrachloroethane	5	µg/L	
1,2-dichloropropane	5	µg/L	
Vinyl chloride	2	µg/L	
Pesticides			
Chlordane	2	µg/L	
Heptachlor	0.4	µg/L	
Heptachlor epoxide	0.2	µg/L	
Toxaphene	5	µg/L	
Methoxychlor	0.1	µg/L	
Endrin	0.0002	µg/L	

References

3 "Man-System Integration Standards" NASA-STD-3000 Vol. 1. Rev.A (1989)
4 "Space Station Freedom Environmental Control and Life Support System Phase III Water Recovery Test
Stage 8. Final Report
D.L. Carter, D.W. Holder, and C.F. Hutchens, NASA Technical Memorandum 108478 (Feb. 1995)
5 "System Specification for the International Space Station Alpha," SSP 41000, 9 February 1994
contract no. NAS15-10000
Boeing Defense and Space Group
Space Station Program Office

APPENDIX B
PHYSICAL PARAMETERS

WATER PARAMETER	UNITS	POTABLE MCL U.S. MCL	POTABLE MCL Russian MCL	HYGIENE MCL U.S. MCL	HYGIENE MCL Russian MCL	Notes
						1
Total dissolved solids	mg/l	100 to 1000		1000	-	2
Color	Pt-Co units/degrees	15	20	15	20	3
Taste	TTN/grade	3	2	-	-	3
Odor	TON/grade	3	2	3	3	3
pH	pH units	5.5 to 9.0		5 to 9	-	4
Turbidity	NTU/mg/l	1	1.5	1	1.5	3
Total Gas	%Volume@1ATM,20°C	5	-	-	-	
Ammonia (NH3-N)	mg/l	2	10	10	-	
Arsenic	mg/l	0.01	-	-	-	
Barium	mg/l	1	-	-	-	
Cadmium	mg/l	0.005	-	-	-	
Calcium	mg/l	100	-	-	-	
Chlorine-total (includes CL-)	mg/l	200	-	350	-	
Chromium	mg/l	0.1	-	-	-	
Copper	mg/l	1	-	-	-	
Fluorine	mg/l	1.5	-	-	-	
Iodine-total(includes I-)	mg/l	15	-	-	-	
Iodine-residual	mg/l	1.0 to 4.0	-	1.0 to 4.0	-	5
Iron	mg/l	0.3	-	-	-	
Lead	mg/l	0.05	-	-	-	
Magnesium	mg/l	50	-	-	-	
Manganese	mg/l	0.05	-	-	-	
Mercury	mg/l	0.002	-	-	-	
Nickel	mg/l	0.1	-	-	-	
Nitrate (NO3-N)	mg/l	10	-	-	-	
Selenium	mg/l	0.01	-	-	-	
Silver	mg/l	0.5	-	0.5 to 2.0	-	6
Sulfate	mg/l	250	-	-	-	
Zinc	mg/l	5	-	-	-	
Total Hardness (Ca & Mg)	meq/l	7	-	-	-	
Total Bacteria	CFU/100ml	100	10000	100	100000	3
Coliform Bacteria	CFU/100ml	<1	-	<1	-	
Virus	PFU/100ml	<1	-	<1	-	
Cyanide	µg/l	200	-	-	-	
Total Phenols	µg/l	1	-	-	-	
Total Organic Carbon (TOC)	µg/l	500	25000	10000	no limit	3
Uncharacterized TOC	µg/l	100	no limit	-	-	
Oxygen consumption-COD	mg/l	no limit	100	no limit	250	3

Notes:
1. MCL: Maximum Contaminant Level
2. The 100 mg/l limit applies to the water before mineralization. After mineralization, this parameter will not exceed 1000mg/l.
3. Parameters have different values for U.S. and Russian-supplied water.
4. pH range applies only before iodination.
5. Range of required level if iodine is used as biocide.
6. Range of required level applies if silver is used as a biocide.

Reference:
Joint U.S./Russian Potable and Hygiene Water Specifications for ISS, from P. Mudgett and R. Sauer.

APPENDIX C

Space Station Microbiology Requirements

[fax, pages 3 - 10, dated May 7, 1996, from Dr. Duane Pierson, JSC]

Microbiology
ISS Environmental Sampling Schedule 6A (or 2R) through Assembly Complete Water (Based on 90 day increments)

Dates	5/98 or 12/98 to 2/02	2/09 to 5/02	5/02 thru Assembly Complete
Flight Module On-board Water System/ Systems	2R or 6A to 11R Service Module-R Russian potable	11R to 17A Life Support Module-R Russian potable and hygiene (separate)	17A HAB-US Russian potable and hygiene U.S. potable/hygiene (single loop)
Points of use/Storage Tanks	• galley (2) hot and cold • SV-2 (ground-supplied water: resupply each 90 days)	• shower or sauna • hand wash	• shower (h/c) • hand wash (h/c) • galley (h/c) • 2 tanks
Sample Source/ Schedule (cumulative)	1) Galley-Hot 2) Galley-Cold each immediately after system is operable and once/week for 30 days; then each once/month for 2 months; then hot OR cold once/month thru assembly complete 3) SV-2 immediately after transfer; thereafter once/month thru assembly complete 4) Archival sample prior to shuttle undock thru assembly complete	Samples 1, 2, 3, 4 plus 5) Hand Wash OR furthest hygiene outlet from the source one, immediately after system is operable and once/week for 30 days; then once/month thru assembly complete 6) Archival sample from hand wash or furthest hygiene outlet from source prior to shuttle undock thru assembly complete	Samples 1 thru 6 plus 7) Galley Cold water 8) Furthest hygiene outlet from the source (FHO) each immediately after system is operable and each location once/week for 30 days; then each location once/month 9) Archival sample from galley cold water or FHO prior to shuttle undock
Total Number of Water Samples and MCDs/90 Days (cumulative)	First 90 days 18 samples incl 1 archival, 34 mcds Day 91 up to 2/02 5 samples incl 1 archival, 8 mcds	First 90 days 8+5 samp incl 2 archivals, 11 mcds Day 91 or 11R up to 17A 3+5 samp incl 2 archivals, 12 mcds	First 90 days 15+8 samp incl 3 archivals, 40 mcds Day 91 or 17A thru assembly complete 7+8 samp, incl 3 archivals 24 mcds

Microbiology
ISS Environmental Sampling Schedule 2R through Assembly Complete Air and Surfaces of Habitable Volumes only (Based on 90 day increments)

Dates	5/98 or 12/98 to 10/99	10/99 to 6/00	6/00 to 5/02	6/02 on
Time Period Module	2R or 6A to 10A • Node 1-US • Service Module-R • LAB-U.S.	10A to 10R • Node 2-U.S. • Research Module 1-R	10R to 17A • Research Module 2-R • HAB-U.S. • Life Support Module-R • Research Module 3-R	17A Assembly Complete • Node 1 • SM • LAB • Node 2 • RM 1 • RM 2 • HAB • LSM • RM 3
Task				
Air Sample Schedule	Each module once/month for 3 months; thereafter, once/3 months	Node 2 and RM 1 once/month for 3 months; thereafter, once/3 months	RM 2, HAB, LSM, and RM 3 once/month for 3 months; thereafter once/3 months	Each module once/3 months
Total Air Samples for 90 days	18 (9 bacteria and 9 fungi) for first 90 days; thereafter, 6 (3 bact and 3 fungi) each 90 days	18 (12+6) (9 bacteria and 9 fungi) for first 90 days; thereafter, 10 (5 bact and 5 fungi) each 90 days	34 (24 + 10) (17 bacteria and 17 fungi) for first 90 days; thereafter, 18 (9 bact and 9 fungi) each 90 days	18 (9 bact and 9 fungi) each 90 days
Surface Sample (2 sites per module)	Node 1, SM, and LAB once/month for 3 months; thereafter once/3 months	Node 2 or RM 1 once/month for 3 months thereafter, once 3/months	RM 2, HAB, LSM, and RM 3 once/month for 3 months; thereafter, once/3 months	Each module once/3 months
Total Surface Samples for 90 days	36 (bact and fungi) (2 sites each module for first 3 months; thereafter, 12 each 90 days	36 (24+12) for first 3 months; thereafter, 20 each 90 days	68 (48+20) for first 3 months; thereafter, 36 each 90 days	36 each 90 days

Preflight Microbiology Requirements for Space Station Environment and Payloads

	Maximum for Bacteria	Maximum for Fungi
Air	300 CFU/m^3	50 CFU/m^3
Internal Surfaces	5 CFU/cm^2	0.1 CFU/cm^2
Water	0 CFU/100 ml	0 CFU/100 ml

Bacteria Culture Conditions: Air & Internal Surfaces
- Incubation Time – 72 hours
- Temperature –37°C
- Growth Medium – Trypticase Soy Agar

Fungi Culture Conditions: Air & Internal Surfaces
- Incubation Time – 7 days
- Temperature – 30°C
- Growth Medium – DG-18 Agar

Total Count: Water
- Membrane Filtration method
- Incubation Time – 7 days
- Temperature – 30°C
- Growth Medium – R2A

Exclusion List

The presence of any of the following microorganisms in the air and on internal surfaces requires identification of the source and the implementation of clean-up countermeasures:

Branhamella catarrhalis	*Blastomyces dermatitidis*
Histoplasma capsulatum	*Corynebacterium JK*
Neisseria meningitidis	*Salmonella* spp.
Streptococcus pyogenes	*Coccidioides immitis*
Aspergillus fumigatus	*Cryptococcus neoformans*

There is no specific exclusion list for the ground supplied water since no microorganisms should be present as shown in the table above.

Inflight Microbiological Sampling for Space Station Air

Parameter	Acceptability Range (CFU/m^3)
Air:	
Total Count	Less than 1000
Air Microorganisms: (1)	
Branhamella catarrhalis	0
Legionella spp.	0
Neisseria meningitidis	0
Salmonella spp.	0
Shigella spp.	0
Streptococcus pyogenes	0
Aspergillus fumigatus	0
Cryptococcus neoformans	0

(1) Requires ground based analysis

Inflight Microbiological Sampling for Space Station Surfaces

Parameter	Acceptability Range (CFU/m^2)
Surfaces:	
Total Bacteria	0 to 40
Total Fungi	0 to 4
Surface Microorganisms: (1)	
Branhamella catarrhalis	0
Klebsiella pneumoniae	0
Pseudomonas aeruginosa	0
Salmonella spp.	0
Shigella spp.	0
Streptococcus pneumoniae	0
Streptococcus pyogenes	0
Aspergillus fumigatus	0
Cryptococcus neoformans	0

(1) Requires ground based analysis

Water Microbial Requirements (Potable and Hygiene Water)

Quality Parameters	Level Colony Forming Unit (CFU)/100 ml
Total Count bacteria/fungi (1)	100
Total Coliform (2)	Non-detectable by method used (3)
Viruses	Non-detectable by method used (4)

(1) Incubation time: 48 hours to 5 days
Temperature: ambient (2R to 17A); 30°C (assembly complete)
Media: R^3A

(2) Incubation time: 48 hours to 5 days
Temperature: ambient (2R to 17A); 30°C (assembly complete)
Media: M-Endo

(3) Membrane Filtration Method

(4) Tissue culture assay

APPENDIX D

Proposed Technology Assessment Metric

PROPOSED TECHNOLOGY ASSESSMENT METRIC (TAM) FOR AIR MONITORING

1 INTRODUCTION

This section presents a metric tool to assist in decision-making exercises regarding the assessment of sensor technologies in space life support. The metric is called the Technology Applicability Metric (TAM). The term "assessment" highlights the fact that the technology must be appropriate or applicable to the specific mission environment. It is therefore distinct from other metrics which rate readiness for space flight.

The primary use for the metric is to pinpoint shortcomings of existing sensors and then either (a) enable the use of the existing technology via focused development or (b) choose instead to develop an entirely new sensor technology. It is recognized that a particular sensor may not score high in all categories, so the metric is useful in identifying areas where further development is needed. A secondary use for the metric is in making choices among various sensor technologies. The parameters used in rating a sensor are (a) Performance (Normal), (b) Performance (Anomalous), (c) Reliability, (d) Maintainability, and (e) Flight Certification. This metric does not address manufacturability or manufacturing cost issues, although it is recognized that these are important factors in making a sensor technology generally available at a reasonable cost.

The metric provides a tiered representation of evaluation levels, so that the evaluation result can easily be presented at each of four levels of detail. The TAM can provide:

A. A single number representation of the overall evaluation
B. An evaluation in each of 4 principle categories
C. A detailed evaluation for every parameter within each principle category
D. Technical detail

A systems engineer may choose calculate only levels A, B, and C, particularly at early stages of sensor development; whereas the design engineer may calculate all necessary levels. Managers may require an evaluation of all levels, but may only use levels A and B for decision-making.

This preliminary metric is proposed for gas phase (air) life-support sensors. The metric is derived from both the work of Gardner [1] who describes microsensors attributes and MIL-HDBK-217 [2] which describes a metric for evaluating the reliability of microelectronic components. It is expected that a very similar metric for water phase will be feasible.

2 SENSOR ENVIRONMENTS

The metric is intended to assess sensors used in the space station environment. That is, sensors are required to operate primarily in a human compatible environment with respect to temperature, pressure, and humidity as listed in Table 2-1.

Table 2-1. Normal Operating Environment

ATTRIBUTE	UNITS	MIN	MAX
TEMPERATURE	°C	20	30
PRESSURE	kPa	69	101
HUMIDITY	%RH	30	70

However, it is recognized that it is desirable for sensors to operate with degraded performance in anomalous environments. Temperature, pressure, and humidity limits are listed in Table 2-2 for anomalous environments. Such environments may occur during explosions, decompression, or loss of environmental controls. In these cases the sensor data is invaluable in diagnosing problems in the same way a flight data recorded is used to diagnose aircraft disasters.

Table 2-2 Anomalous Environment

ATTRIBUTE	UNITS	MIN	MAX
TEMPERATURE	°C	-200	100
PRESSURE	kPa	0	1000
HUMIDITY	%RH	0	90
TOTAL RADIATION DOSE	rad	TBD	TBD
POWER LOSS	mW	TBD	TBD
CONTAMINATION	mg/l	TBD	TBD

The metric can be weighted to favor the sensor's performance in either the normal or the anomalous environment. It is important for the extreme operating limits for a sensor to be understood. It may not be required for a sensor to operate during an anomaly but to be operable after an anomaly to provide current environmental status.

3 SENSOR PARAMETERS

The parameters used in rating a sensor are (a) Performance (Normal), (b) Performance (Anomalous), (c) Reliability, (d) Maintainability, and (e) Flight Certification. The attributes for each of the parameters are listed in Tables 3-1 to 3-5. These tables provide a framework for the calculation of the metric. A description of the metric is given in the next section. This section is devoted to listing the attributes which are further described in the a follow-on section.

Given the nominal operating environment listed in Table 2-1, the sensor technology must have the capability or performance listed in Table 3-1. The usage of the Table is as follows: the Mission Environment requirement for each parameter is listed in the third column. In the forth column the sensor performance value of the given sensor technology is listed. The attribute is assigned a score of 0 to 4, using the scale described below:

0 Requirement not met. No useful data obtainable.

1 Requirement not met, but some minimal useful data or other utility obtainable. <u>Example</u>: at 29°C, sensor accuracy falls to ±20%.

2 Requirement not met, but substantial useful data or other utility is obtainable, or the sensor is otherwise "close" to meeting the requirement. <u>Example 1</u>: the sensor functions for 50% of its lifetime

requirement. Example 2: the sensor is 10% more massive than the requirement.

3 Requirement met.

4 Requirement exceeded in a usable capacity. Example: the mass requirement is 5 kg, and the sensor has a mass of 0.5 kg. This frees up 4.5 kg of mass allocation. Counter example: Sensor is accurate to 0.01 ppb, but the background noise level of the measured environment is 1 ppb (such a sensor would receive a rating of 3, not 4, for accuracy).

The total score is the sum of the scores for each attribute. The parameter score is the average for the attributes scored. Note that if an attribute is not applicable, it may be excluded from the calculation.

Table 3-1 Evaluation table for Sensor Performance during Normal Environments (P_1).

ATTRIBUTE	UNITS	MISSION REQUIREMENT	SENSOR VALUE	SCORE 0 - 4
RANGE*	ppm			
SENSITIVITY*	x/ppm			
RESOLUTION*	±x ppm			
ACCURACY*	±%			
RESPONSE TIME	s			
RECOVERY TIME	s			
LINEARITY	%			
SAMPLING RATE	Hz			
MASS	kg			
VOLUME	cm^3			
POWER	mW			
TOTAL SCORE				
PARAMETER SCORE				

Technologies which detect multiple compounds will generally have separate range, sensitivity, resolution, and accuracy requirements. The sub-attributes marked with * can be evaluated following a table similar to Table 3-1a.

Table 3-1a Example Performance Range Table for Target Gases found on the Shuttle. Similar tables would be created for sensitivity, resolution, and accuracy.

Compound	Detected on shuttle (ppm) [3]	SMAC (ppm) [4-5] 1hr / 7day	MISSION REQ. RANGE	SENSOR RANGE	SCORE 0 - 4
alcohols					
methanol	< 1	30 / 7			
ethanol	.5 - 5	---			
2-propanol	.4 - 4	400 / 60			
methane	1 - 10	5300 /5300			
ammonia	0	30 / 0			
benzene	< .1	10 / 0.5			
CO_2	320	13000 /700			
formaldehyde	0	0.4/ 0.4			
Freon 113	.1 - 1	50 / 50			
hydrazine	0	4 / .04			
indole	0	1 / .05			
toluene	.4 - 4	16 / 16			

An example of the sensitivity of gas sensor sensitivity to various gases is listed in Table 3–1a for the STS (Space Shuttle) environment where the SMAC (Spacecraft Maximum Allowable Concentration) is given along with the concentrations detected on the Shuttle. As presented in the table, gas sensitivities need in general to be less than one ppm (part per million). Table 3-1a illustrates that the range, sensitivity, resolution, and accuracy attributes can have a number of subtopics that must be scored.

Table 3-2 Evaluation Table for Sensor Capability/Performance after an Anomaly (P_2).

ATTRIBUTE	UNITS	MISSION REQUIREMENT	SENSOR VALUE	SCORE 0 - 4
RANGE*	ppm			
SENSITIVITY*	x/ppm			
RESOLUTION*	±x ppm			
ACCURACY*	±%			
RESPONSE TIME	s			
RECOVERY TIME	s			
LINEARITY	%			
SAMPLING RATE	Hz			
MASS	kg			
VOLUME	cm^3			
POWER	mW			
TOTAL SCORE PARAMETER SCORE				

For the anomalous environment listed in Table 2-2, it is desired that the sensor have the performance listed in Table 3-2. Notice that after an anomalous event it is most important that the sensor function but it may have reduced capability. In case of an anomaly, the most important parameter could be power. That is, a battery powered sensor, with a daily recharge cycle, could be operational after an anomaly and capable of reporting on current conditions.

Sensor reliability requirements are listed in Table 3-3 for the normal environment.

Table 3-3. Evaluation Table for Sensor Reliability (P_3)

ATTRIBUTE	UNITS	MISSION REQUIREMENT	SENSOR VALUE	SCORE 0 - 4
CAL DRIFT	mV			
CAL INTERVAL	weeks			
ZERO DRIFT	mV			
LIFETIME	MTTF			
CONTAMINATION				
INTERFERENCE				
SINGLE EVENT UPSET	upset/bit -day			
TOTAL SCORE				
PARAMETER SCORE				

Sensor maintainability requirements are listed in Table 3-4 for the normal environment.

Table 3-4 Evaluation Table for Sensor Maintainability (P_4)

ATTRIBUTE	UNITS	MISSION REQUIREMENT	SENSOR VALUE	SCORE 0 - 4
CALIBRATION INTERVAL	weeks			
CALIBRATION TYPE				
-- SELF CALIBRATION				
-- STD LAB				
MAINTENANCE INTERVAL	weeks			
EASE OF REPAIR				
TOTAL SCORE				
PARAMETER SCORE				

The sensor must be capable of passing the Human Rating Requirements in order to be flight certified. Some key parameters are listed in Table 3-5, a more comprehensive list is given in other NASA documents. It is expected that most sensors will rate highly in this category.

Table 3-5. Evaluation Table for Sensor Flight Certification (P_5)

ATTRIBUTE	UNITS	MISSION REQUIREMENT	SENSOR VALUE	SCORE 0 - 4
RF BROADCAST				
SAFETY: FIRE				
SAFETY: ELECTRIC SHOCK				
SAFETY: SHARP EDGES				
RADIATION PRODUCED				
ELECTROSTATIC DISCHARGE				
TOTAL SCORE				
PARAMETER SCORE				

4 RATING METRIC

The decision-making metric, M, for space life support sensors is a weighted average algorithm.

$$M = \frac{w_1 P_1 + w_2 P_2 + w_3 P_3 + w_4 P_4 + w_5 P_5}{w_1 + w_2 + w_3 + w_4 + w_5} = \frac{\sum_i w_i P_i}{\sum_i w_i}$$

where each parameter P_i has a value between zero and four for each of the parameters given in Tables 3-1 to 3-5 and w_i is a weighting factor with a value between zero and one that is applied by the systems engineer to weight the importance of each of parameter. For example, if there is no requirement to have the sensor operate through an anomaly then $w_2 = 0$.

The parameter, P_i, is determined by first setting the requirements for each of the attributes listed in Tables 3-1 to 3-5. Then a value for each sensor attribute is recorded in the tables. Next, each attribute, A_{ij}, is given a score between zero and four, following the criteria given above. Then, P_i is the arithmetic average of the scores A_{ij}. A perfect score is M=4, where all A_{ij}, all $P_i = 4$, and all w_i 's = 1.

Note: Not all attributes given here may be relevant to a particular mission environment, and some additional attributes may be necessary.

Figure 1 is a schematic showing the tiered nature of the metric.

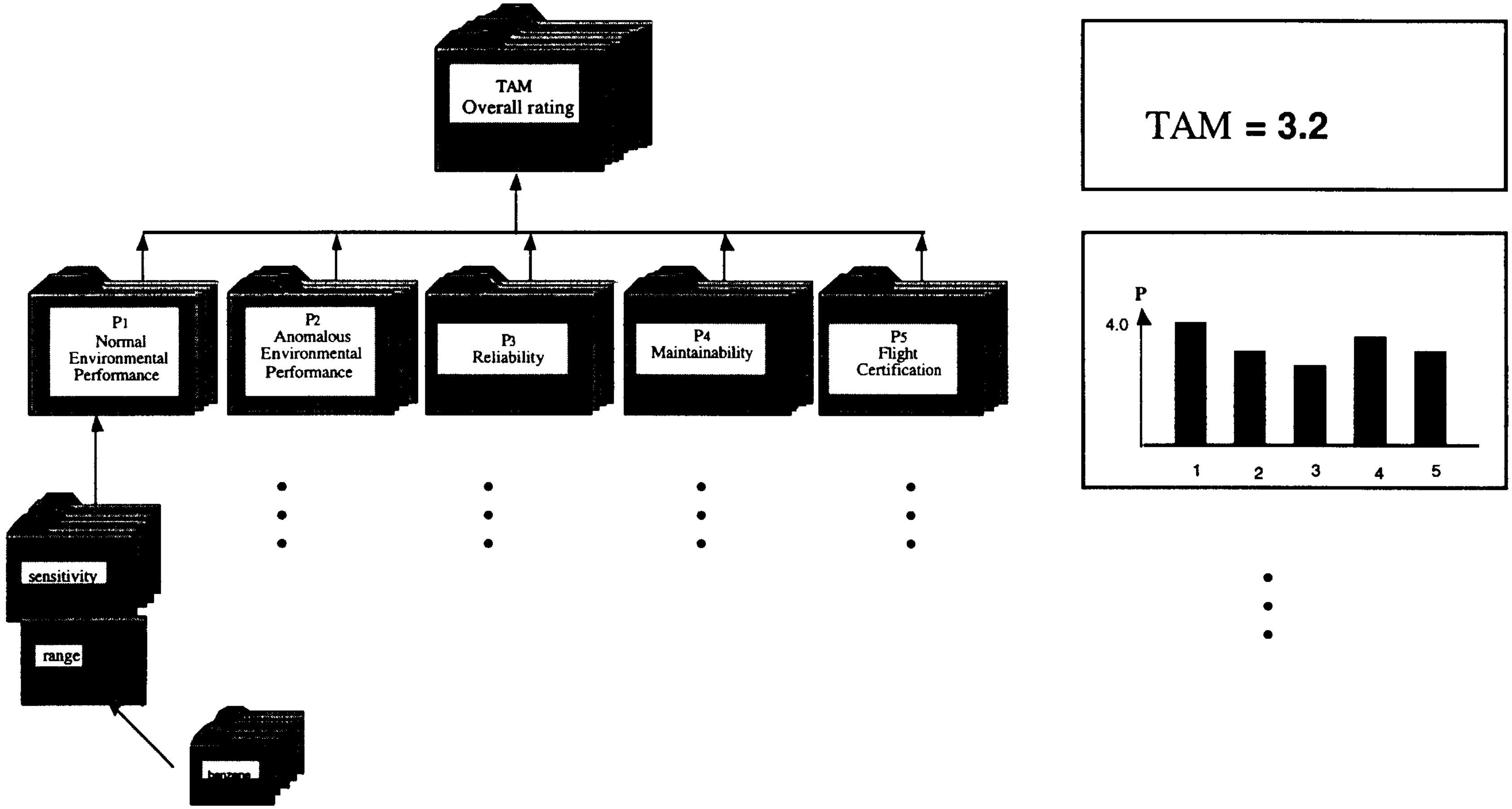

Figure 1 Schematic of metric calculation process. Results, at right, can be examined at various levels of detail: The top level is a single number; the next level of detail can be shown as a bar graph; further levels of detail are also documented.

5 SUMMARY/DISCUSSION

A metric has been presented which evaluates space life support air monitoring sensor technologies for their relevance and applicability to given mission environments. The method is tiered, so that the sensor evaluation can be examined at various levels of detail, from full detailed specifications, to tables of numbers, to a bar graph, and finally a single number on a 0 to 4 scale.

This metric remains to be tested in actual mission applications. Such testing may be performed on past as well as future missions, and is welcome and necessary in order to establish maturity for the metric.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
May 1996

3. REPORT TYPE AND DATES COVERED
Ongoing Report

4. TITLE AND SUBTITLE
Advanced Environmental Monitoring and Control Program Technology Development Requirements

5. FUNDING NUMBERS

6. AUTHOR(S)
Darrell Jan, Panchalam Seshan, Gani Ganapathi, Gregory Schmidt, and Charles Doarn, editors.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

8. PERFORMING ORGANIZATION REPORT NUMBER
JPL D-13832

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
NASA HQ Code ULS
Washington, D.C.

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
TM 4755

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Human missions in space, from the International Space Station on towards potential human exploration of the moon, Mars and beyond into the solar system, will require advanced systems to maintain an environment that supports human life. These systems will have to recycle air and water for many months or years at a time, and avoid harmful chemical or microbial contamination. NASA's Advanced Environmental Monitoring and Control program has the mission of providing future spacecraft with advanced, integrated networks of microminiaturized sensors to accurately determine and control the physical, chemical and biological environment of the crew living areas.

This document sets out the current state of knowledge for requirements for monitoring the crew environment, based on (1) crew health, and (2) life support monitoring systems. Both areas are updated continuouslythrough research and space mission experience. The technologies developed must meet the needs of future life support systems and of crew health monitoring. These technologies must be inexpensive and lightweight, and use few resources. Using these requirements to continue to push the state of the art in miniaturized sensor and control systems will produce revolutionary technologies to enable detailed knowledge of the crew environment.

14. SUBJECT TERMS
Launch Vehicles and Space Vehicles/Laboratories, Test Facilities, and Test Equipment/Aerospace Medicine/ Life Support/ Environmental Monitoring

15. NUMBER OF PAGES
53

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL